HYDROLOGY AND PLANKTON OF COASTAL WATERS AT NAPLES, FLORIDA

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In characterizing a marine environment ecologically, studies of aquatic conditions (Harvey, 1957; Rochford, 1951) and plankton as indicator organisms (Cleve, 1900; Russell, 1939) are extremely important.

The object of this work was to make concurrent studies of plankton occurrence and hydrology as well as to determine the influence of precipitation on them. Occurrence of the red-tide organism, *Gymnodinium breve* Davis (1948), was of particular interest in this study, since the Florida red tide is a natural fish-killing phenomenon in the coastal waters of southwest Florida. Monthly variations in temperature, salinity, total phosphate phosphorus, inorganic phosphate phosphorus, nitrate-nitrite nitrogen, substances which react to tests for arabinose and tyrosine, and characteristic plankton forms were investigated. A second objective was to observe the influence of precipitation upon the hydrology and plankton.

In recent years, the chemical and biological properties of Gulf waters of the west coast of Florida have been studied by various authors (Gunter *et al.,* 1948; Lasker and Smith, 1954; Ketchum and Keen, 1948; King, 1950; Graham *et al.,* 1954; Graham, 1954; Collier, 1958a; Curl, 1959a, 1959b; Finucane and Dragovich, 1959; Pomeroy, 1960; Dragovich *et al.*, 1961), but very little simultaneous hydrological and planktonic information is available for southwestern Florida waters.

The data on which this study is based have been published elsewhere (Dragovich, 1961).

Materials and Methods

All water samples were collected from the surface at Naples Pier, Naples, Florida, latitude 26° 07.9′, longitude 81° 48.5′. Sample collection procedure, plankton counting technique, and chemical methods of analysis were those described by Dragovich (1961). Organisms were enumerated in the living state. All Florida identifications and distributions not otherwise ascribed are by the au-

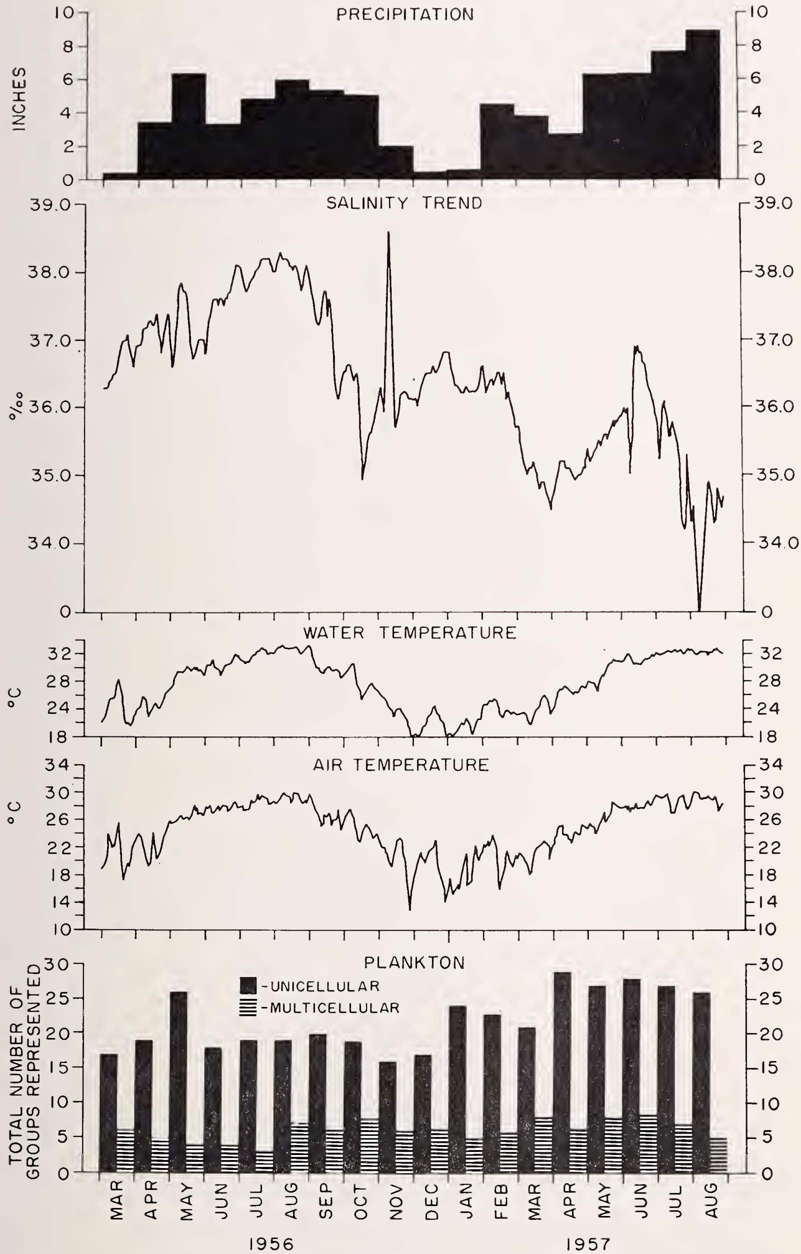

Fig. 1. Precipitation, salinity, water temperature, air temperature, and plankton for the surface water at Naples, Florida, March 1956-August 1957.

thor. Notes on species and distributions in other Gulf of Mexico waters not otherwise ascribed are from unpublished records of the Biological Laboratory of the Bureau of Commercial Fisheries at Galveston, Texas. When another source is also cited, these unpublished data will be indicated by (BCF).

HYDROLOGICAL OBSERVATIONS

The maximum (31.9° C.) water temperature was recorded in August 1956 and the minimum (17.0° C.) in November 1956 and January 1957. The monthly mean temperatures varied from 19.5° C. in January 1956 to 30.8° C. in August 1956. A relatively sharp rise occurred from April to May 1956 and a sharp decline from October to November 1956 (figure 1). Unusual spells of warm weather were recorded during March-April 1956 and from December 1956 through February 1957. During the remaining portion of this investigation, the seasonal temperature changes were gradual. The air temperature varied from 7.5° C., in January 1957, to 30.8° C., in July 1956. The monthly distribution of water temperature was essentially that of the air temperature (figure 1).

The monthly salinity means varied from 34.4 o/oo in August 1957 to 38.0 o/oo in August 1956. From March 1956 to August 1956 a gradual increase in salinity was noted. From August 1956 to August 1957 there was a generally declining trend.

The year 1956 was characterized by relatively little precipitation (38.1 inches), whereas the year 1957 had heavy rainfalls (58.4 inches). The 20-year mean precipitation for the Naples area is 51.50 inches. Precipitation values in figure 2 are the means of monthly rainfall recorded at weather centers in Naples, Miles City Tower, Everglades, and Fort Myers. Fort Myers, Everglades, and Miles City Tower are located within a 38-mile radius to the north, south, and east of Naples, respectively. All four of these weather centers are within the drainage basin of Everglades swamps, which drain their waters into the Gulf of Mexico.

The concentrations of total phosphorus in 69 water samples collected over a period of 17 months varied from 0.2 to 17.4 microgram atoms per liter (μg.at./l) with a mean of 1.5 μg.at./l (Dragovich, 1961). The highest concentrations during 1956 were observed in March and April. From April 1956 to May 1957 the concentrations remained below 2.0 μg.at./l. Unusually high values

Fig. 2. Incidence of plankton at Naples, Florida, March 1956-August 1957.

(17.4 and 12.7 μg.at./l) were recorded in May and June 1957. During July, the concentrations remained below 2.0 μg.at./l.

The frequency distribution of total phosphate phosphorus concentrations shows that the majority of values (69.6 per cent) ranged from 0.2 to 1.0 μg.at./l. In 20.3 per cent of observations the values ranged from 1.1 to 2.0 μg.at./l, but the range 2.1 to 17.4 μg.at./l was recorded in only 10.1 per cent of the samples.

Concentrations of inorganic phosphate phosphorus in 73 samples varied from 0.0 to 3.2 μg.at./l with a mean of 0.6 μg.at./l. With the exception of May and June 1957, the monthly distribution pattern of inorganic phosphate phosphorus was similar to that of the total phosphate phosphorus. The frequency distribution of values showed a range of 0.1 to 0.6 μg.at./l in 68.5 per cent of the samples; 0.7 to 1.0 μg.at./l in 19.2 per cent; and 1.1 to 3.2 μg.at./l in 12.3 per cent.

Concentrations of nitrate-nitrite nitrogen in 66 water samples collected in a period from May 1956 to July 1957 ranged from 0.0 to 4.4 μg.at./l, with a mean of 0.7 μg.at./l. The monthly distribution of nitrate-nitrite nitrogen was very irregular. Highest concentrations were observed during November 1956 and March 1957. The distribution of nitrate-nitrite nitrogen values shows that the majority of concentrations (62.1 per cent) varied from 0.0 to 0.6 μg.at./l. A range of 0.7 to 2.0 μg.at./l was observed in 33.3 per cent of the samples. High values (2.1 to 4.4 μg.at./l) were recorded in only 4.5 per cent of the samples collected during November 1956 and March 1957. The minimal nitrate-nitrite nitrogen values of 0.0 μg.at./l were recorded in 6.1 per cent of samples and occurred during July, August, and October 1956.

Concentrations of carbohydrates producing a positive arabinose test in 73 samples varied from 0.0 to 4.1 milligrams per liter (mg/l) with a mean of 1.2 mg/l, and total tyrosine in 71 water samples varied from 0.0 to 10.5 mg/l, with a mean of 1.1 mg/l. These carbohydrate and protein substances will be referred to hereafter simply as carbohydrates and proteins.

The monthly mean values of carbohydrates and proteins were irregular. The concentrations of carbohydrates during 1956, with the exception of some values in March, April, and December, exceeded those of proteins. In 1957, extremely high concentrations of proteins were observed during February, March, and July, at which time proteins greatly exceeded carbohydrates. The concentrations of carbohydrates were generally lower during 1957 than during 1956. The frequency distribution of carbohydrates and proteins showed that the majority (66.2 per cent) of protein concentrations varied from 0.0 to 0.6 mg/l, and the majority (63.0 per cent) of carbohydrate concentrations ranged from 0.7 to 2.0 mg/l.

Plankton Observations

The study included 48 unicellular and 13 multicellular taxa of plankton (Dragovich, 1961). The unicellular taxa consisted of 10 genera of diatoms, 26 genera of dinoflagellates (11 of which were identified to species), a group of silicoflagellates, a group of unidentified phytoplankton (5-12 μ in size), 2 euglenoid genera, 6 ciliate genera, 1 ciliate family, and 1 unidentified group of ciliates.

Diatoms were represented by five centrate genera: *Chaetoceros* Ehrenberg, *Guinardia* Perag, *Melosira* Agardh, *Rhizosolenia* (Ehrenberg, Brightwell) Perag, and *Skeletonema* Greville; and five pennate genera: *Thalassiothrix* Cleve and Grunow, *Navicula* Bory, *Nitzschia* Hassal, *Pleurosigma* W. Smith, and *Grammatophora* Ehrenberg. All genera consisted of several species. No species identification was made.

Chaetoceros, Melosira, and *Nitzschia* were the principal diatom genera observed, occurring every month during this investigation.

Chaetoceros, the most frequently occurring group of diatoms, was present in 49 per cent of all observations (figure 2). Although *Chaetoceros* spp. appeared throughout the observation period, their

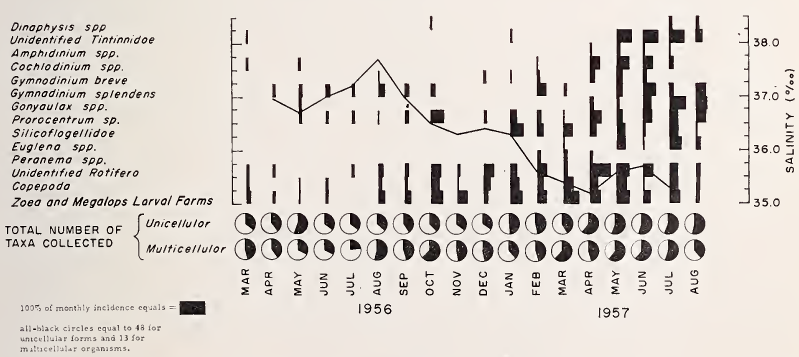

Fig. 3. Monthly incidence of selected planktonic groups, total number of taxa collected, and the salinity trend at Naples, Florida. Salinity trend represented by a three-item moving average of monthly salinity means.

presence in large numbers was noted only from May through September 1956.

Melosira and *Nitzschia,* the second and third most frequently observed groups of diatoms, showed similar monthly occurrence.

Rhizosolenia and *Guinardia* were present during most months, and blooms of these two groups were recorded during May 1956. A larger *Rhizosolenia,* resembling *R. styliformis* Brightwell, was on the whole, much scarcer than a smaller species.

Skeletonema and *Pleurosigma* had very limited occurrence. *Pleurosigma* occurred in small numbers. *Skeletonema* was predominant during April 1957.

Grammatophora appeared only during spring and summer months of 1957, occurring most frequently in April.

Navicula appeared during 9 months but never in high numbers.

Thalassiothrix was observed only in June and July of 1956 in small numbers.

The data indicate an influx of diatoms in May, June, August, and September of 1956. High concentrations of diatoms were observed in 1956, but 1957 was characterized more frequently by low concentrations.

Among dinoflagellates, the principal groups of organisms were *Gymnodinium* Stein, *Peridinium* Ehrenberg, and *Gyrodinium* Kofoid and Swezy (figure 2).

Gymnodinium spp. ranged from 5 to 40 μ. The smallest resembled *G. vitiligo* Ballantine and *G. veneficum* Ballantine; the largest resembled *G. heterostriatum* Kofoid and Swezy. *Gymnodinium* spp. occurred during every month; their abundance was consistently high from January through August 1957 at periods of reduced salinity and high precipitation.

The three gymnodinians identified to species are *G. splendens* Lebour, *G. simplex* Lohmann, and *G. breve* Davis.

G. splendens. Neritic and estuarine species. Common off west coast of Florida; off Galveston coast, Texas; and off Plymouth Sound, England (Lebour, 1925). Occurred during 13 months of the observation period. Monthly incidence higher during comparable months of 1957 than of 1956, except for April. Absence noted during November, December 1956 and January 1957, the period of lowest temperatures (figure 1).

G. simplex. Neritic and estuarine species. Common off west coast of Florida and Galveston, Texas. Observed in Adriatic Sea

(Ercegović, 1936), Plymouth Sound and at Kiel (Lebour, 1925). Appeared at Naples in January and April 1957 at the period of lower salinity and cooler temperatures *G. simplex* occurred in unusually large numbers (up to 10,000 per ml).

G. breve. Neritic and estuarine species. Observed in an area from Tarpon Springs, Florida, to Ten Thousand Islands off Everglades, and extending 40 miles offshore (Finucane and Dragovich, 1959; Dragovich *et al.,* 1961). Recorded from lagoons near Galveston, Texas. At Naples, present only in low concentrations. Occurred during August and December 1956 and first half of 1957.

Peridinium spp. made up the second most frequently occurring group of dinoflagellates. Frequency of occurrence was considerably higher during 1957 than in comparable months of 1956. Three peridinians were identified to species, *P. divergens* Ehrenberg, *P. depressum* Bailey, and *P. diabolus* Cleve. The identification of *P. diabolus* is questionable.

P. divergens. Neritic species. Observed in Norwegian and Danish seas, English Channel, Adriatic Sea, Bosporus, California (Lebour, 1925), and off Australian coast (Wood, 1954). Common in waters of west coast of Florida; present at Naples in higher numbers only during June 1956 and July 1957. Highest incidence observed during July and August 1957 during a period of low salinities.

P. depressum. Oceanic species. Common in North Sea, Atlantic Ocean, Indian Ocean, and Mediterranean Sea (Lebour, 1925). Observed in Adriatic Sea (Ercegović, 1936), off the east coast of New Zealand (Cassie, 1960), and off the west coast of Florida (BCF; Curl, 1959b). Recorded at Naples during May and September 1956; and June, July, and August 1957. Highest frequency of occurrence recorded during July 1957 at a period of low salinities and great heterogeneity in phytoplankton species composition.

P. diabolus. Oceanic species. Observed in Atlantic, Mediterranean, Plymouth Sound (Lebour, 1925), and off east coast of Australia (Wood, 1954). Occurred at Naples only in small numbers during March and May 1956.

Gyrodinium spp. comprised one of the principal dinoflagellate groups recorded during this investigation. Although found in every month, they occurred more frequently in the samples during 1957 than in comparable months of 1956, except for April.

G. spirale Berg, was the only gyrodinian identified to species.

Known for world wide distribution (Lebour, 1925). Present only during April and May 1956 in minimal numbers.

The genus *Ceratium* Schrank was represented by *C. furca* Ehrenberg, *C. tripos* O. F. Muller, and *C. fusus* Ehrenberg.

C. furca. Neritic species. Observed in northern temperate Atlantic to English Channel, Baltic Sea (Lebour, 1925), Norwegian Sea (Hasle and Nordli, 1951), South Pacific (Cassie, 1960), North Sea (Lucas, 1942), and off the west coast of Florida (BCF; King, 1950; and Curl, 1959b). Occurred during every month of the investigation with the exception of July 1956. Frequency of occurrence higher during 1957 than in comparable months of 1956, appearing in high numbers only during December.

C. tripos. Oceanic species. Observed in North Sea (Lucas, 1942), Norwegian Sea (Hasle and Nordli, 1951), English Channel (Lebour, 1925), South Pacific (Cassie, 1960), and off west coast of Florida. Present at Naples only during August 1957 in small numbers.

C. fusus. Oceanic species. Observed in all oceans (Curl, 1959b). Fairly common in coastal waters of west Florida; occurred at Naples only in small numbers during June, August, and September 1956.

Prorocentrum sp., resembling *P. micans* Ehrenberg, was present during 15 months of this investigation, occurring more frequently in samples during 1957 than in comparable months of 1956. During August 1957, *Prorocentrum* sp. was present in large numbers. The actual count of organisms during these blooms was 100 to 1,000 cells per ml. These blooms occurred in the period of lowest salinities accompanied by high temperatures and high organic phosphate phosphorus content. *Prorocentrum* sp. is common in the coastal waters of west Florida and in East Lagoon, Galveston, Texas.

The genus *Exuviella* Cienkowski was represented by several species, which are listed under *Exuviella* spp. Most of the organisms resembled *E. compressa* (Bailey) Ostenfeld. *Exuviella* spp. were present in small numbers, occurring during 8 months of the observation period. They were recorded most frequently during December 1956 and January 1957. *Exuviella* spp. are common in coastal waters from Tarpon Springs to Cape Sable, Florida.

Peridiniopsis Lemmermann. *Peridiniopsis* spp. occurred through the observation period, but never in high numbers.

Torodinium Kofoid and Swezy. *Torodinium* spp. were never present in high numbers, but they appeared in the samples during 10 months of the observation period, including January through June of 1957.

Gonyaulax Diesing. *Gonyaulax* spp. were recorded only once during 1956. In 1957, their presence was noted from April until the end of the investigation, a period of reduced salinities. Their highest concentrations were attained in June 1957.

Cochlodinium Schutt. *Conchlodinium* spp. were scarce during 1956. In 1957, they were more frequently observed, occurring during February, April, May, June, and July.

Polykrikos Butschli. *Polykrikos* spp. had a monthly distribution similar to that of *Conchlodinium* spp.

Amphidinium Claparede and Lachmann. *Amphidinium* spp. occurred only from April through July 1957, the period of relatively low salinities, in small numbers.

Dinophysis Ehrenberg. *Dinophysis* spp. occurred in small numbers in October 1956 and July 1957 during the periods of salinity decline. Blooms of *Dinophysis* spp. were recorded in August 1957, when salinity was low.

Dinophysis tripos Gourret. Oceanic form. Observed in Norwegian Sea, Greenland Sea, Indian Ocean, Mediterranean (Lebour, 1925), Australian region (Wood, 1954), and in the coastal waters off west Florida. Rare at Naples, appearing only during October 1956.

Oxyrrhis Dujardin. This genus was represented by one species, which resembled *O. marina* Dujardin, and was very scarce.

Nematodinium Kofoid and Swezy and *Pouchetia* Schutt (emended by Kofoid and Swezy) was represented by a few species. They occurred only during the spring months of 1956 in small numbers.

Two euglenoid groups of organisms and a chrysomonad group, belonging to the family Silicoflagellidae, were also observed at Naples. *Euglena* and *Peranema* first appeared during the spring months of 1957, which were characterized by the onset of the rainy season and a salinity decline. *Peranema* spp. were present in samples from February through April. *Euglena* spp. were observed in March and from May until the end of the observation period. The highest numbers of *Euglena* spp. were recorded during June and July.

After a complete absence during 1956, blooms of silicoflagellates, resembling *Distephanus speculum* (Ehrenberg) Haeck, appeared in January 1957. Thereafter, although the numerical prominence of these silicoflagellates never attained blooming proportions, they were present in the samples until the end of the observation period.

Unidentified phytoplankton, 5-12 μ in size, were very numerous during every month of this investigation. Most of these cells were generally translucent, yellowish green, somewhat round in shape, and occasionally flagellated. This was the most common group of organisms observed during this study, occurring in 85.2 per cent of observations (figure 2). Despite their minute size, they appear to be a prominent constituent of the plankton.

The most frequently occurring group of ciliates is listed as unidentified species. This assemblage of various species ranged in length from 5 to 80 μ. The smallest organism resembled *Mesodinium pulex* Claparede and Lachmann, while the largest resembled members of the families Frontonidae and Euplotidae. Unidentified ciliates were recorded during every month of the observation period. Consistently high numerical representation was recorded from September 1956 until April 1957 when other ciliates were also prominent.

Vorticella Fromental was the second most frequently observed group of ciliates. Its absence in samples was noted only during June 1956. The highest frequency of occurrence was attained in January. *Vorticella* spp. were most common from July 1956 to May 1957. The shallow investigation area provides an excellent environment for telotrochs and sessile vorticellids.

Tintinnopsis Stein was the third most frequently occurring group of ciliates (figure 2). This genus was present during 14 months of this investigation. Blooms of *Tintinnopsis* spp. were observed during December 1956 and January 1957. These organisms were most common from October 1956 to April 1957. The remaining members of the family were listed as unidentified Tintinnidae. With the exception of March 1956, their presence was observed exclusively during 1957. Their maximum incidence in samples was attained during May 1957.

Ranking fourth in frequency of occurrence among ciliates were the Halteriidae. This group of ciliates occurred more frequently during the comparable months of 1956 than 1957. Blooms were observed during November 1956, and January and March 1957. *Strombidium* Claparédè and Lachmann sp. was the only further identified member of the Halteriidae.

Strombidium sp. occurred in small numbers and was present during the winter and spring months of 1957.

Cothurnia Ehrenberg and *Pleuronema* Dujardin were present only during 1956 in small numbers.

Multicellular plankton, or zooplankton, consisted of copepods, rotifers, ostracods, chaetopods, coelenterates and larval stages of crustaceans, mollusks, annelids, echinoderms, and fishes.

Copepods were very common in samples but never present in high numbers. Their absence was noted only during April and July of 1956. Their maximum frequency of occurrence was observed in March 1957.

Ostracods appeared only during June 1957 and were present in high numbers.

Rotifers, consisting of a variety of species, were listed as unidentified rotifers. They appeared to be a significant segment of multicellular plankton (figure 2), occurring in 26.2 per cent of the samples. With the exception of August, they were noted more frequently during 1957 than in comparable months of 1956. *Synchaeta* Ehrenberg and *Proales* Ehrenberg were listed separately. *Synchaeta* sp. appeared in small numbers and only during August 1956. *Proales* sp. was the only rotifer to attain dense population during this investigation.

Free-swimming coelenterate medusae and echinoderm larvae were very irregular in occurrence, appearing only in small numbers.

Chaetopods, resembling *Dinophilus* Schmidt, were recorded during March, April, and May 1957, a period of high form diversity in other plankton.

Crustacean larvae made up the most commonly observed larval group. Zoea and megalops larval stages were absent only during June and July of 1956. Their frequency of occurrence was greater during the spring months of 1957 than in those of 1956. The temporal occurrence of nauplii was continuous.

Veliger larvae, present during 11 months, never occurred in high numbers. Their frequency of occurrence was greater during 1957 than in comparable months of 1956.

Trochophore larvae were present only during September 1956 in small numbers.

Fish larvae occurred very irregularly during 11 months, always in small numbers.

TABLE 1

SURFACE CONCENTRATIONS OF PHOSPHATE PHOSPHORUS IN MARINE WATERS

Locality	PO_4-P Minimum	(μg. at./l) Maximum	Mean	Source of Information
South Atlantic Coast of the United States (April 1954)	0.0	1.8	0.3	Anderson and Gehringer (1958)
South Atlantic Coast of the United States (June, July 1954)	0.1	2.4	0.7	Anderson and Gehringer (1959a)
South Atlantic Coast of the United States (September 1954)	0.0	1.4	0.0	Anderson and Gehringer (1959b)
Gulf of Mexico	0.0	5.3	0.2	Collier (1958b)
English Channel	0.03	0.74		Harvey (1957)
Calicut-West Coast of India	0.13	1.68		Subrahmanyan (1959)
Florida West Coast	0.0	2.5	0.3	Finucane and Dragovich (1959)
Florida West Coast	0.0	9.4	1.2	Dragovich, Finucane, and May (1961)
Naples, West Coast of Florida	0.0	3.2	0.6	Present investigation

DISCUSSION

The particular collection and examination method used in the present study permitted the detection of small, fragile forms, including *Gymnodinium breve,* which does not readily survive collection by plankton net or brass water sampling bottle.

King (1950), in his plankton studies of coastal waters of west Florida, observed six diatom genera (*Skeletonema, Navicula, Nitzschia Rhizosolenia, Chaetoceros,* and *Thalassiothrix*) and eight dinoflagellate genera (*Gymnodinium, Gonyaulax, Peridinium, Prorocentrum, Cochlodinium, Polykrikos, Ceratium,* and *Dinophysis*), which we also noted. The same author reported that water samples from river, bay, and coastal areas off Boca Grande, Florida, usually yielded large numbers of *Gymnodinium simplex* when cultured in the laboratory. The present work shows that this organism also occurred in extremely high numbers at Naples. In regard to tintinnids, copepods, ostracods, rotifers, and mollusk larvae, King's observations were in general agreement with our findings. On the other hand, he found much better representation of copepods and diatoms than the fragile phytoplankton forms. He collected plankton with both reversing water bottle and plankton net, preserving the samples in formalin.

For his phytoplankton study of Apalachee Bay and the northeastern Gulf of Mexico, Curl (1959b) detected a greater variety of diatoms than was observed in the present study, but only one non-thecated dinoflagellate. He usually preserved one liter of water with neutralized formalin and concentrated samples in a Forest plankton centrifuge. Ciliates and euglenoid organisms were not mentioned in his report.

The difference between our results and those of Curl and King may be attributed largely to differences in methods of collection and treatment of samples. In regard to detection of non-thecated dinoflagellates, ciliates, and euglenoids, examination of living organisms has advantages over preserved samples. However, this type of sampling method seems not to have any advantage in collection of large multicellular plankton.

Since the author's identifications of most of the plankton were carried out only to family, genus, or listed as unidentified, the plankton probably consisted of a much larger number of species than we list. This should stimulate those who wish to engage in taxonomic plankton studies of the west coast of Florida.

TABLE 2

INCIDENCE OF PLANKTON BY TEMPERATURE INTERVALS

Temperature Range (°C.)	17.0–23.5	23.6–28.4	28.5–31.9
Number of Observations	126	120	120*
UNICELLULAR PLANKTON:			
Amphidinium spp.	0	5	2
Cochlodinium spp.	5	18	10
Gymnodinium breve	3	9	5
G. simplex	2	1	0
G. splendens	9	18	29
G. spp.	89	105	104
Gyrodinium spirale	1	3	0
G. spp.	46	74	53
Torodinium spp.	8	10	5
Polykrikos spp.	7	3	11
Nematodinium spp.	1	0	1
Pouchetia spp.	0	2	0
Oxyrrhis spp.	1	0	0
Ceratium furca	31	18	18
C. fusus	0	3	4
C. tripos	0	0	1
Gonyaulax spp.	1	7	26
Peridiniopsis spp.	7	10	23
Peridinium depressum	2	1	4
P. diabolus	1	1	0
P. divergens	2	5	17
P. spp.	70	74	80
Dinophysis tripos	0	1	0
D. spp.	0	1	6
Exuviella spp.	9	5	4
Prorocentrum sp.	13	32	24
Silicoflagellidae	20	15	11
Euglena spp.	0	6	25
Peranema spp.	4	4	0
Melosira spp.	40	54	38
Skeletonema spp.	0	1	0
Chaetoceros spp.	39	58	86
Guinardia spp.	4	18	6
Rhizosolenia spp.	2	28	9
Thalassiothrix spp.	0	1	2
Navicula spp.	3	6	1
Pleurosigma spp.	1	0	0
Nitzschia spp.	17	30	31

TABLE 2 (cont.)

INCIDENCE OF PLANKTON BY TEMPERATURE INTERVALS

Temperature Range (°C.)	17.0–23.5	23.6–28.4	28.5–31.9
Number of Observations	126	120	120*
UNICELLULAR PLANKTON: (Cont.):			
Grammatophora spp.	1	4	1
Unidentified Phytoplankton	118	120	85
Strombidium sp.	3	3	0
Unidentified Halteriidae	26	28	12
Tintinnopsis spp.	58	42	13
Unidentified Tintinnidae	3	9	31
Vorticella spp.	62	52	33
Cothurnia sp.	1	3	0
Pleuronema sp.	0	1	0
Unidentified ciliates	100	104	68
Coelenterata	1	0	5
Proales sp.	0	1	2
Synchaeta sp.	0	0	1
Unidentified Rotifera	27	42	27
Echinoderm larvae	2	3	2
Veliger	8	11	2
Chatetopoda	0	7	0
Trochophore	1	0	0
Copepoda	27	24	18
Ostracoda	0	1	1
Nauplii	25	26	12
Megalops and Zoea	49	35	21
Pisces larvae	5	5	4
BROAD PLANKTON GROUPS:			
Dinoflagellates	308	406	427
Silicoflagellates } *Peranema* spp. }	24	19	11
Euglena spp.	0	6	25
Diatoms	107	200	174
Unidentified phytoplankton	118	120	85
Ciliates	253	242	157
Multicellular plankton	145	155	95

* Number of observations in regard to *Gymnodinium breve* was 125.

Scatter diagrams indicate no correlation between the broad plankton groups (dinoflagellates, diatoms, ciliates, unidentified phytoplankton, silicoflagellates, euglenoids, and zooplankton) and hydrological parameters (temperature, salinity, inorganic phosphate phosphorus, total phosphate phosphorus, nitrate-nitrite nitrogen, carbohydrates, and proteins).

The subtropical annual temperature range of 17.0 to 31.9° C. observed at Naples is comparable to that of Tampa Bay (Dragovich *et al.*, 1961) and to the Apalachee Bay waters of northern Florida (Curl, 1959a). A close parallel between the air and the water temperatures was noted (figure 1). Rapid changes in water temperature occurred during the winter and early spring months but were less pronounced than in Texas bays (Collier and Hedgpeth, 1950) or Tampa Bay (Dragovich *et al.*, 1961). In order to compare the occurrence of plankton constituents with the temperature, the entire temperature data were subdivided into three categories, each of which included about one-third of the total number of observations (table 2). Dinoflagellates, *Euglena* spp., and diatoms occurred more frequently at the higher end of the Naples water temperature range, and the unidentified phytoplankton, ciliates, silicoflagellates, *Peranema* spp., and multicellular plankton were more frequent at the lower end.

Pronounced salinity differences between the relatively dry year of 1956 and the relatively wet year of 1957 were observed. However, the monthly salinity distribution does not show an inverse relationship to the precipitation. This was particularly noticed during November, December, and January. The absence of this relationship may indicate that the waters at Naples are influenced more by the coastal water circulation than by direct fresh-water runoff. The values for Naples show deviation both above and below 35.0o/oo, which may be assumed to be a representative salinity value for the open Gulf. However, the frequency distribution of salinity values showed that in only 6.6 per cent of the observations were the salinities below 35.0o/oo, while in 93.4 per cent of observations they ranged from 35.0o/oo-38.6o/oo, indicating that coastal waters off Naples are marine. The salinity range observed at Naples can be classified as euryhaline (30.0o/oo-40.0o/oo). The temporal salinity distribution indicates that change is more characteristic than steady state for this area. Such changes are typical of coastal waters.

The plankton occurrence was compared with salinities in a manner analogous to the temperature-plankton comparison (table 3). All broad plankton groups occurred with greater frequency at the lower end of the Naples salinity range, with the exception of diatoms and unidentified phytoplankton. A number of taxa, notably several dinoflagellates (including *G. breve*), Tintinnidae, silicoflagellates, and euglenoids, were observed only, or most frequently, in this range.

Higher incidence of certain plankton forms and higher taxonomic diversity of the plankton as a whole occurred during the lower salinity months of 1957 (fig. 3). Abundance of phytoplankton during periods of salinity decline has also been observed in other areas (Bigelow, 1926; Gaarder and Gran, 1927). Dissolved nutrients in land drainage (Wilson and Collier, 1955) and external metabolites (Lucas, 1955; Wilson, 1951; Wilson and Armstrong, 1952) are factors which are thought to be responsible for the greater prominence of plankton at the periods of lower salinity. Thus, salinity reduction *per se* may not have been the decisive factor in proliferation of plankton. However, the salinity tolerances of coastal planktonic organisms observed during this study may have enabled them to take advantage of the availability of nutrients during periods of reduced salinity (Braarud and Rossavik, 1951).

The Florida red-tide organism was never observed to bloom during the period of this study, although the data of Dragovich *et al.* (1961) indicate that *G. breve* occurred in blooming proportions during October and November 1957, in coastal waters less than 8 miles off Naples Pier. The occurrence of *G. breve* was more frequent during 1957 than in comparable months of 1956 (figure 3). In the absence of *G. breve* blooms, the present results do not give evidence of a planktonic succession that may be associated with the development of the Florida red tide. This observation is in agreement with that made by Gunter *et al.* (1948).

The temporal distribution of total phosphorus was characterized by great fluctuations in March and April 1956, and May and June of 1957 (Dragovich, 1961). Possible explanations for the high total phosphorus levels noted are (1) proximity to land drainage outlets, in which high phosphorus concentrations exist, and (2) stirring of the bottom sediment by wind (Harvey, 1957). The absence of an inverse salinity-phosphorus relationship favors the latter possibility. The mean total phosphorus value observed at Naples

TABLE 3

Incidence of Plankton by Salinity Intervals

Salinity Range (o/oo)	32.4–36.0	36.1–36.9	37.0–38.6
Number of Observations	121*	121	115
Unicellular Plankton:			
Amphidinium spp.	5	1	0
Cochlodinium spp.	20	9	2
Gymnodinium breve	9	4	1
G. simplex	1	2	0
G. splendens	19	20	16
G. spp.	107	99	84
Gyrodinium spirale	0	0	4
G. spp.	42	52	71
Torodinium spp.	9	7	5
Polykrikos spp.	12	7	2
Nematodinium spp.	0	1	1
Pouchetia spp.	0	1	1
Oxyrrhis spp.	0	0	1
Ceratium furca	28	27	12
C. fusus	4	2	1
C. tripos	1	0	0
Gonyaulax spp.	25	6	1
Peridiniopsis spp.	13	10	15
Peridinium depressum	4	3	1
P. diabolus	0	1	1
P. divergens	9	5	10
P. spp.	107	74	41
Dinophysis tripos	0	1	0
D. spp.	7	0	0
Exuviella spp.	5	9	4
Prorocentrum sp.	35	24	8
Silicoflagellidae	28	16	0
Euglena spp.	23	5	0
Peranema spp.	4	3	0
Melosira spp.	34	48	44
Skeletonema spp.	1	0	0
Chaetoceros spp.	58	57	65
Guinardia spp.	9	8	10
Rhizosolenia spp.	15	5	14
Thalassiothrix spp.	0	0	2
Navicula spp.	1	6	3
Pleurosigma spp.	1	0	0

TABLE 3 (cont.)

INCIDENCE OF PLANKTON BY SALINITY INTERVALS

Salinity Range (o/oo)	32.4–36.0	36.1–36.9	37.0–38.6
Number of Observations	121*	121	115
UNICELLULAR PLANKTON (Cont.):			
Nitzschia spp.	23	22	30
Grammatophora spp.	5	1	0
Unidentified phytoplankton	83	113	117
Strombidium sp.	4	2	0
Unidentified Halteriidae	40	19	6
Tintinnopsis spp.	45	43	20
Unidentified Tintinnidae	31	7	3
Vorticella spp.	42	60	40
Cothurnia sp.	0	1	3
Pleuronema sp.	0	0	1
Unidentified ciliates	89	93	82
MULTICELLULAR PLANKTON:			
Coelenterata	1	0	4
Proales sp.	1	1	1
Synchaeta sp.	0	0	1
Unidentified Rotifera	46	35	9
Echinoderm larvae	4	2	1
Veliger	10	7	3
Chaetopoda	4	0	0
Trochophore	0	1	0
Copepoda	33	25	6
Ostracoda	0	1	0
Nauplii	23	23	17
Megalops and Zoea	51	34	14
Pisces larvae	8	4	3
BROAD PLANKTON GROUPS:			
Dinoflagellates	462	365	282
Silicoflagellates, *Euglena* spp., *Peranema* spp.	55	24	0
Diatoms	147	147	168
Unidentified phytoplankton	83	113	117
Ciliates	251	225	155
Multicellular plankton	181	133	59

* Number of observations in regard to *Gymnodinium breve* was 126.

Pier was two to three times higher than the corresponding values (0.6 μg.at./l) recorded at the 4-fathom contour off Naples (Finucane and Dragovich, 1959).

The highest inorganic phosphate phosphorus values occurred during March, April, November, and December 1956. The seasonal cycle in inorganic phosphate phosphorus observed in northern latitudes (Harvey, 1957) was not evident. The concentrations of phosphate phosphorus from various marine areas shown in table 1 are comparable to that for Naples. The maximum values observed at Naples exceed all other corresponding values, except those for two other Gulf of Mexico studies.

Concentrations of organic phosphorus were determined by subtracting the inorganic from total phosphate phosphorus, as determined in simultaneously collected samples. Organic phosphorus averaged 45.5 per cent of the total. The concentrations of organic phosphorus varied considerably from sample to sample and showed no consistent change in regard to the inorganic phosphate phosphorus. High values for inorganic and organic phosphorus may also have resulted from the lack of sample filtration.

The temporal distribution of nitrate-nitrite nitrogen was very irregular. The nitrate-nitrite nitrogen data indicate that the levels observed at Naples are very low if compared to certain marine areas such as the English Channel (Cooper, 1937), Sea of Calcutta (Panikkar and Jayaraman, 1953), Gulf of Maine (Rakestraw, 1936), or Barents Sea (Kreps and Verjbinskaya, 1930). Low levels of nitrate-nitrite in the coastal waters of west Florida were also observed by Finucane and Dragovich (1959) and Dragovich *et al.* (1961). Complete depletion of nitrate-nitrites during July, August, and October 1956 may be ascribed to phytoplankton utilization. Nevertheless, scatter diagrams for various groups of phytoplankton and nitrate-nitrite nitrogen show no relationship.

The existence of other chemical factors in the sea, which affect phytoplankton metabolism, has been postulated by various authors (Lucas, 1955; Wilson, 1951; Wilson and Armstrong, 1952; Collier *et al.*, 1953). The concentrations of carbohydrates and proteins in this study showed an erratic distribution. Collier (1958a) postulated that highly uneven distribution of carbohydrates and proteins might be related to the uneven distribution of marine microorganisms (Barnes and Marshall, 1951; Bainbridge, 1953), but scatter diagrams for various groups of plankton and carbohydrates and proteins showed no relationship.

This ecological investigation has characterized the shallow coastal waters at Naples as a subtropical, marine environment subject to considerable variation in precipitation and in several ecologically important factors. Dinoflagellates, unidentified phytoplankton, and ciliates were the most prominent representatives of unicellular plankton, and copepods and crustacean larvae were the most frequently observed multicellular plankton. The incidence and population density of *G. breve* were very low. Further taxonomic and quantative plankton work might show more definite relationships between the hydrological conditions and the resident biota.

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Summary

During the course of this investigation, temperature, salinity, total phosphate phosphorus, inorganic phosphate phosphorus, nitrate-nitrite nitrogen, substances which react to the test of arabinose and tyrosine, and plankton composition were determined weekly in the coastal surface waters of Naples, Florida. The temperature variations were characterized by relatively sharp changes from April to May and from October to November. During the remaining months, the temperature changes were gradual. A striking effect of air temperature on water temperature was noted. Marked salinity differences were observed between the summer months of 1956 and 1957.

Phosphate levels were two to three times higher than in the adjacent offshore waters at the 5-fathom curve. Unusually high concentrations of total phosphate phosphorus were noted in May and June 1957, during heavy rainfalls. Nitrate-nitrite nitrogen levels at Naples were low compared with those of other marine areas of the world. The seasonal occurrence of organic substances, which react to the test of arabinose and tyrosine, was very erratic.

The plankton composition consisted of 48 unicellular and 13 multicellular taxa. The unicellular taxa or phytoplankton were represented by 10 genera of diatoms, 26 genera of dinoflagellates

(11 of which were identified to species), a group of unidentified phytoplankton (5-12 μ in size), 2 euglenoid genera, 6 ciliate genera, 1 ciliate family, and a group of unidentified ciliates. Copepods, rotifers, ostracods, chaetopods, coelenterates and larval stages of crustaceans, mollusks, annelids, echinoderms, and fishes constituted the multicellular plankton or zooplankton.

The incidence of plankton was considerably higher during the spring and summer months of 1957 than during the corresponding periods of 1956. This difference is associated with a disparity in rainfall and salinity during the spring and summer months of 1956 and 1957. There was no correlation observed between the various groups of plankton and hydrological parameters.

The particular collection and examination method employed during this investigation seems to have certain advantages over collecting by net and examining preserved samples.

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